CAAM/NEUR 415: EXAMINATION #2

December 6, 2008

1 Answer the following questions (total 27 points):

1. You are given electron micrographs of a synaptic junction between two cells and after counting the number of release sites, you determine that there are approximately 50 of them. Is this synapse most likely between two pyramidal neurons of visual cortex or between a motoneuron and a muscle cell? Briefly justify your answer (2 points)
2. Connect the following visual processing areas by an arrow according to the sequence in which visual information successively propagates from the periphery towards more central areas: V1, Retina, MT and LGN. Briefly describe for each area the typical response properties of spiking neurons in that area (one sentence per area; 6 points).
3. You have invented a new technique that allows you to record intracellularly from pyramidal neurons in visual cortex in vivo and then the exact same neuron in a slice preparation. You notice a large increase in input resistance of the neuron in slice when compared to its in vivo value. What is the most likely cause of this increase in input resistance and why? (3 points).
4. Two excitatory inputs onto a neuron generate excitatory postsynaptic potentials of 3 and 4 mV at the soma, respectively. If both inputs are activated simultaneously, what do you expect approximately the depolarization at the soma to be, and why? Assume that the neuron is passive (no active conductances; 3 points).
5. You record from a neuron in area MT of the monkey. In response to an upward moving grating it generates an average of 20 spikes and its spike distribution closely matches a normal distribution with a standard deviation of 4 spikes. For downward motion, the mean is 30 spikes and the standard deviation is again 4 spikes. A second neuron responds with a mean of 50 spikes for downward motion and 60 spikes for upward motion, with a standard deviation of 5 spikes in both cases. You are to guess, using this information, the direction of motion from the spikes elicited in one trial, each direction being equally probable. Which one of the two neurons will provide you with the most accurate information (lowest error rate) and why (3 points)?
6. What are typical values for the coefficient of variation of visual cortical neurons in vivo? Can you briefly explain why these values are significant? (3 points)
7. Which of the following two stimuli do you expect to generate more spikes in an ON-center retinal ganglion cell and why? 1) a bright spot in the center of the receptive field presented simultaneously with a bright spot in the surround; or, 2) the same bright spot in the center but a dark spot in the surround. (3 points)

8. Briefly explain how the receptive fields of simple and complex cells arise according to the Hubel and Wiesel model. A sketch would be useful. (4 points)

2 Theory and practice of Fourier transforms (total 26 points)

1. The Fourier transform of the odd temporal Gabor filter

$$g_o(t) = \frac{1}{\sqrt{2\pi}\sigma_t} e^{-t^2/2\sigma_t^2} \sin k_t t$$

is given by

$$\hat{g}_o(\omega_c) = \frac{1}{2i}(e^{-\sigma_t^2(\omega_c - k_t)^2/2} - e^{-\sigma_t^2(\omega_c + k_t)^2/2}).$$

Plot g_o for $k_t/2\pi = 8$ cycles/s and $\sigma_t = 31ms$. Use 512 points centered at $t = 0$ and a sampling step of 1 ms (4 points).

2. Compute the corresponding Nyquist frequency and sampling step in the frequency domain (4 points).
3. Briefly explain why the Nyquist frequency is an important concept (3 points).
4. Plot $\hat{g}_o$ as a function of frequency (not circular frequency) using the sampling step determined above (4 points).
5. The Fourier transform of g_o is purely imaginary, do you see why? (2 points)
6. Numerically Fourier transform $g_o(t)$ and show that you can reproduce the result of 4 (6 points).
7. Briefly explain the convolution theorem and its significance. (3 points)

3 Threshold fatigue LIF model (total 30 points)

We want to study a leaky integrate-and-fire (LIF) neuron with threshold fatigue. The model consists of a standard leaky integrate-and-fire neuron with a time constant of 20 ms and a capacitance of 2 nF. The initial threshold for spiking is set at 8 mV above rest and the membrane potential is reset to its resting value after a spike. In contrast to the standard leaky integrate-and-fire model, the threshold is not static: immediately after each spike it is incremented by 4 mV and then relaxes exponentially towards its initial value (8 mV above rest) with a time constant of 80 ms.

1. What is the input resistance of the LIF model? (2 points)
2. Write down the two first order differential equations governing the time course of the membrane potential and spike threshold between successive spikes. Give the initial conditions for both equations and the update following a spike. (4 points)

3. Implement the code for these two equations in Matlab and simulate the model's response to a 500 ms long, 2 nA current pulse. Use a forward Euler numerical integration scheme and a time step of 0.1 ms. (8 points)
4. Can you explain in your own words why the pattern of spikes that you are seeing arises? (2 points)
5. Simulate the model's response to a random current injection. The current at each time step (dt = 0.1 ms) is selected independently from a Gaussian distribution with a mean of 1 nA and a standard deviation of 1.5 nA. Plot 500 ms of the random current, the associated membrane potential and spikes. (5 points)
6. Plot an histogram of the interspike interval distribution and compute its coefficient of variation. (3 points)
7. Compute the correlation coefficient at lag 1 of the interspike interval distribution. (4 points)
8. Can you use your own words to explain how the observed value arises? (2 points)

4 Effect of half-wave rectification and gain control on the responses of Gabor filters to moving gratings (total 20 points)

Assume that the response of a directionally selective simple cell to moving gratings is described by

$$R_{rect}(t) = R_{max} \frac{\lfloor R_1(t) \rfloor_+^2}{\sigma^2 + \lfloor R_1(t) \rfloor_+^2} \tag{1}$$

where

$$\lfloor R \rfloor_+ = \begin{cases} R & \text{if } R \geq 0, \\ 0 & \text{if } R < 0, \end{cases}$$

and

$$R_1(t) = R_{spont} + R_c(t) \quad \text{with} \quad R_c(t) = \int dx\, dt_0\, g_e^-(x, t_0) c(x, t - t_0).$$

The parameters are: $R_{spont} = 10$ spk/s, $\sigma = 60$ spk/s and $R_{max} = 120$ spk/s. The spatio-temporal receptive field is given by

$$g_e^-(x, t) = \frac{1}{2\pi\sigma_x\sigma_t} e^{-x^2/2\sigma_x^2 - t^2/2\sigma_t^2} \cos(k_x x - k_t t)$$

with $\sigma_x = 0.1$ deg, $k_x/2\pi = 4.2$ c/deg, $\sigma_t = 31$ msec and $k_t/2\pi = 8$ c/sec.

1. Plot R_{rect} as a function of R_1. Use values of R_1 between 0 and 150 spk/s. (6 points)
2. Compute and plot the response $R_{rect}(t)$ for a grating given by $c(x, t) = \cos(\eta_x x \pm \eta_t t)$ moving either to the left or to the right. Use the parameters $\eta_x/2\pi = 4$ c/deg and $\eta_t/2\pi = 8$ c/sec and a time interval of motion of 2000 ms. (14 points)